High Efficiency HF Power Amplifiers

Implications for New Systems

February 13, 2014
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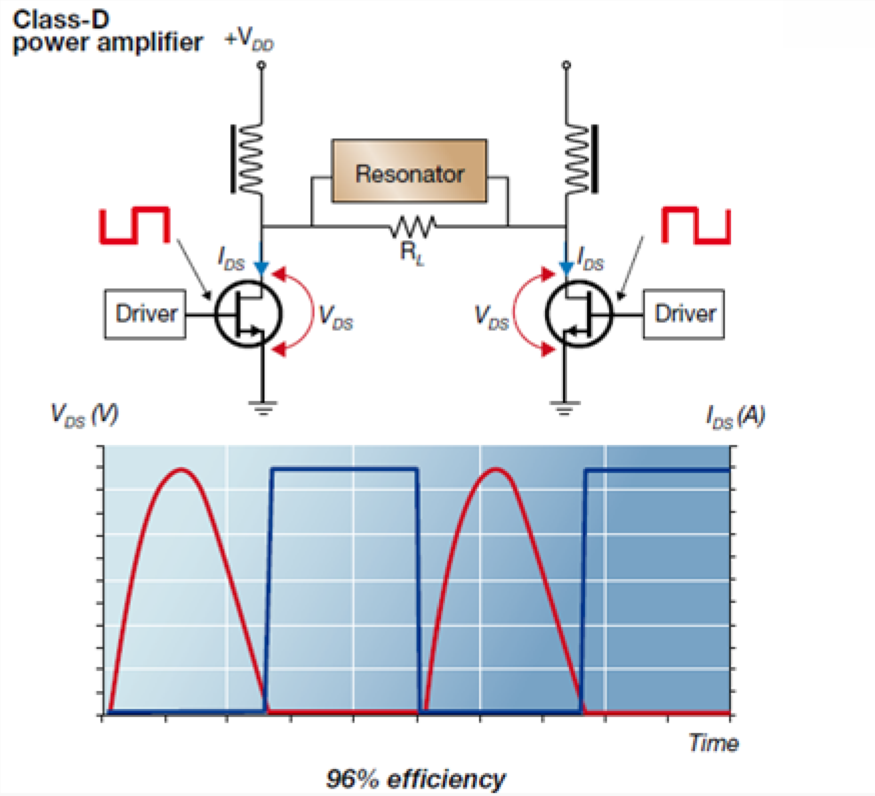
Power Amplifier Efficiency and Its Effect on the Communication System

- Efficiency of a system is defined as the ratio of power output to power input
- Inefficiency of a system defines the power dissipated in the PA as a function of power output.
- Use of inefficient power amplification results in:
  - Higher power consumption, shorter battery life, higher energy costs
  - Larger or more amplifier devices
  - More thermal management
  - Reduced reliability of amplifier components

- Introduction of GaN FET and Si MOSFET devices for switching power conversion make application as high efficiency HF PA practical.

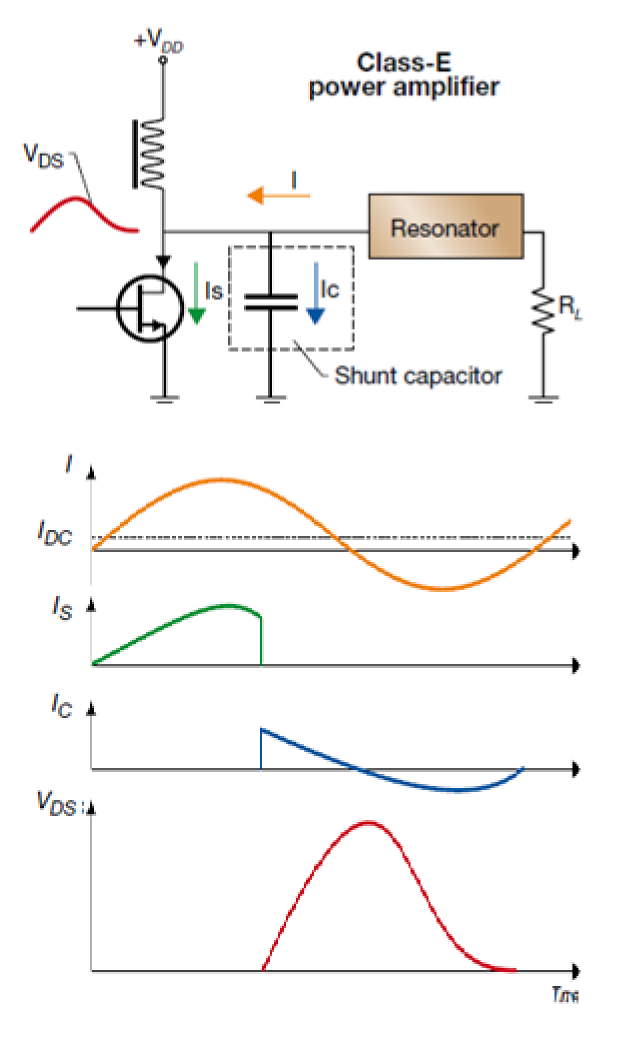
Class-D Power Amplifier

- Class-D power amplifier utilizes switching devices operating as switches.
- The drain voltage waveform is an approximate square-wave, and the current a half sine-wave.
- Theoretical efficiency approaches 100%
- Bandwidth is theoretically bound by (half-octave) harmonic filter



Class-E Power Amplifier

- The Class-E power amplifier uses the active device as a switch within a tuned circuit, generating a damped sinusoidal drain voltage waveform.
- While not capable of the same power-per device as is capable from Class-D, it is operable at higher frequencies.
- Instantaneous Bandwidth is theoretically limited to one octave, practical limitation is one half this.



Class-DE Power Amplifier

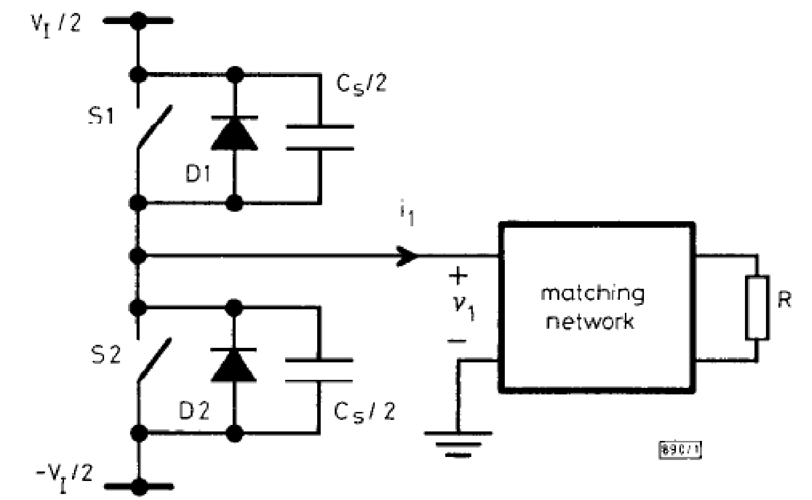


Fig. 1 *Generalised class DE amplifier*

Alipov, A. and Kozyrev, V. ‘Push-Pull Class DE Switching Power Amplifier’

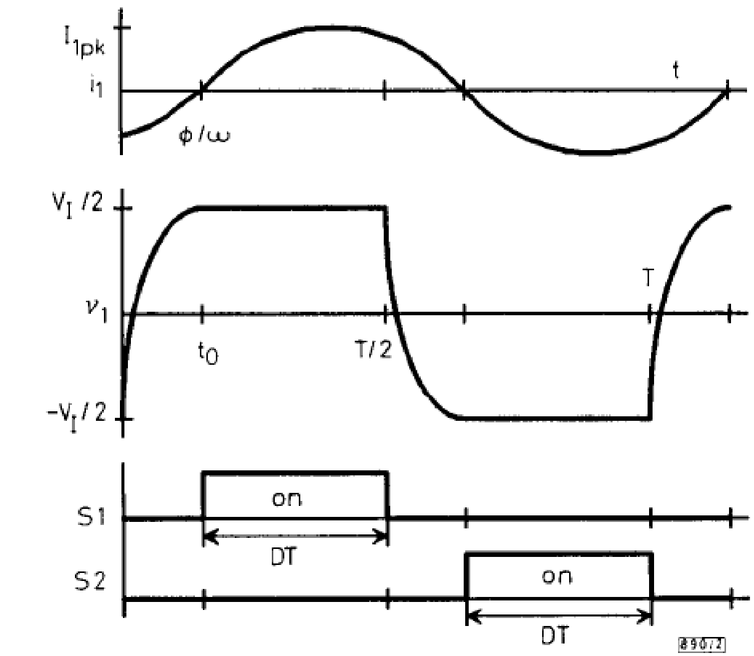


Fig. 2 *Class DE waveforms*

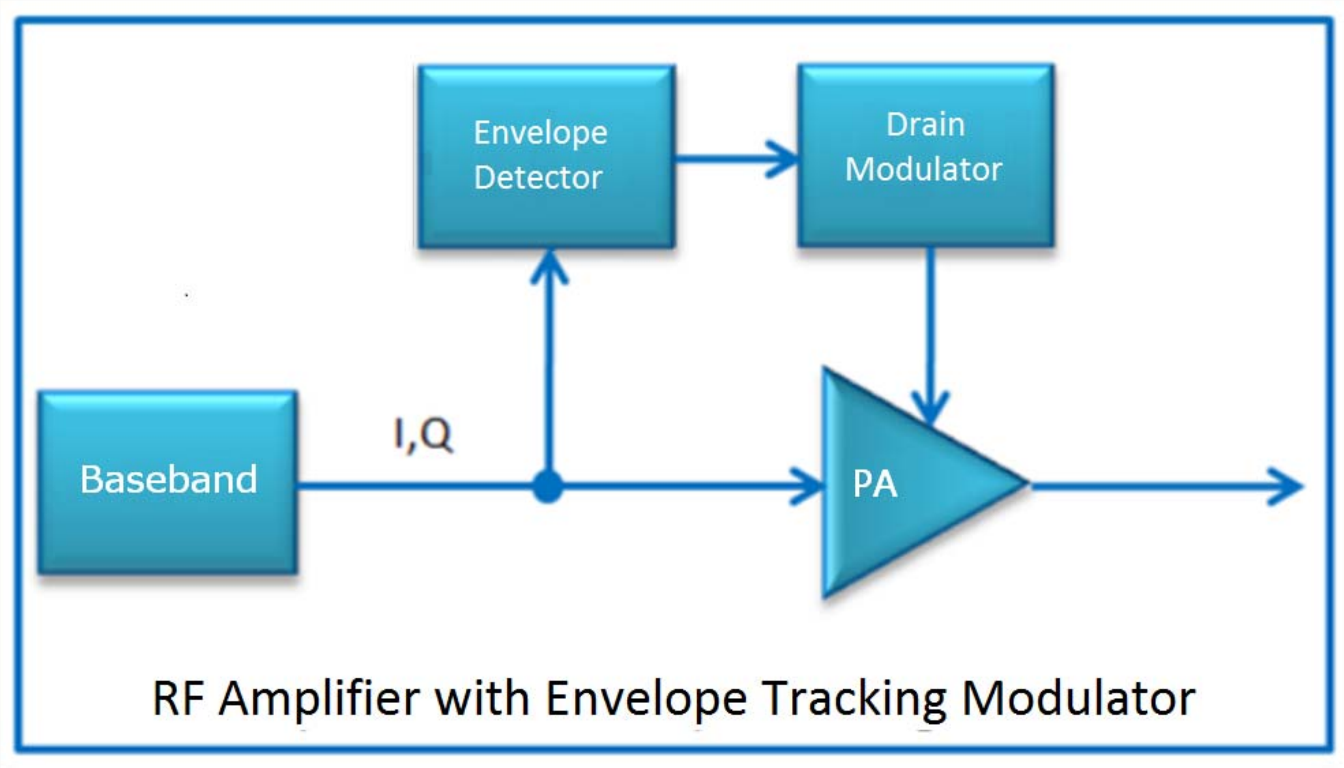
- Class-DE circuit drives devices for less than 180 degree conduction, tunes load inductive so that C_{oss} is resonantly charged to V during device ‘off’ interval, ‘soft-switching’.
- Operates more efficiently than either Class D or E.

Modulating the High-Efficiency PA

- Since these efficient switching power amplifiers are essentially CW amplifiers, reproducing only the phase information of the signal, it is necessary to devise means to efficiently modulate their amplitude.

- Possible techniques include
  - Envelope Elimination and Restoration, (EER)
  - Outphasing (LINC)
  - RF Pulse-Width Modulation

Envelope Elimination and Restoration

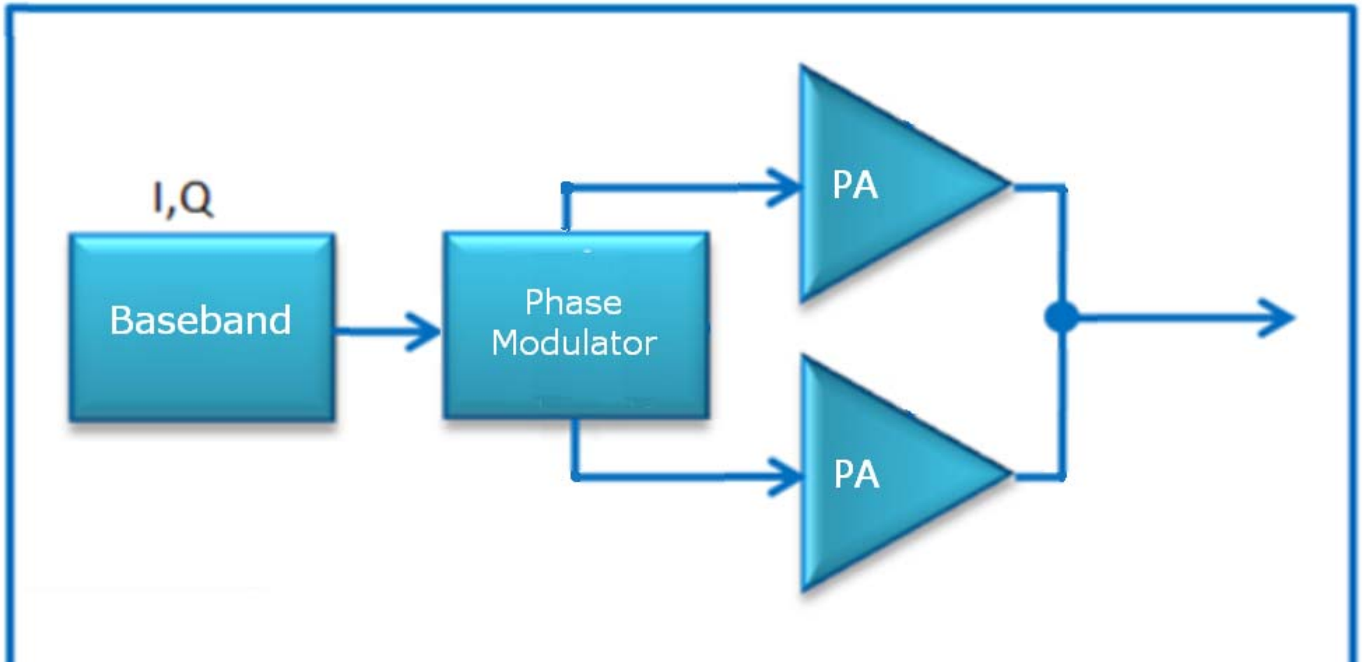


- External switching power converter Drain Modulator efficiently provides modulated envelope signal as supply voltage to switching power amplifier.
- Technique is useable at any PA frequency.

EER Limitations

- The bandwidth of the envelope signal can be >10x the bandwidth of the complex baseband signal.
- The PWM switching converter for the Drain Modulator must switch at >10x bandwidth of the envelope signal so that the PWM components can be successfully filtered out.
- The bandwidth of the PWM drive signal to the Drain Modulator must have bandwidth >10x the PWM switch frequency to preserve PWM fidelity.
- For baseband modulation bandwidths much beyond 1% of carrier frequency, the Drain Modulator switch devices must be selected to have comparable Ft as the PA.

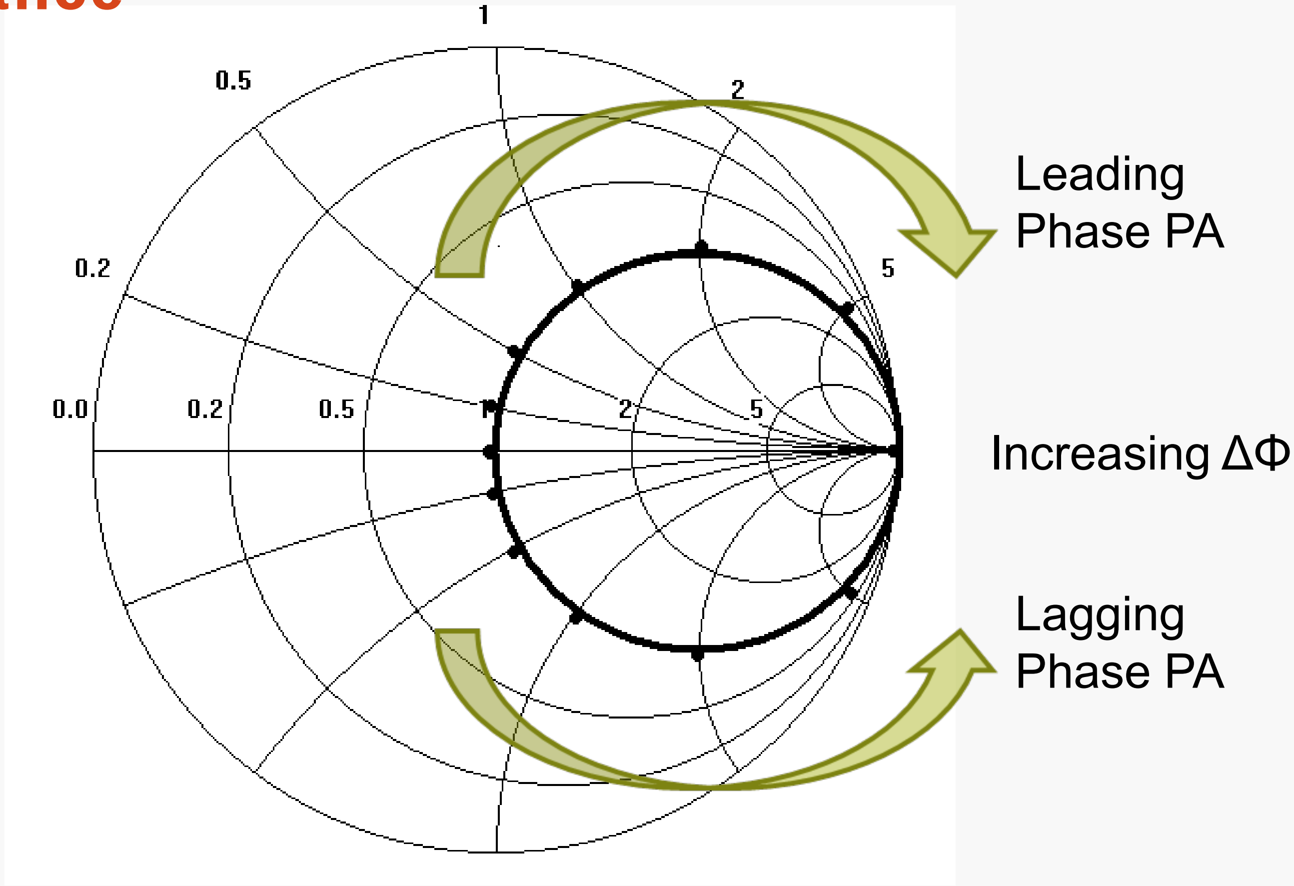
Complex Modulation through Outphasing



RF Amplifiers with Outphasing Modulation

- Summing the outputs of two, phase-modulated switching power amplifiers permits amplitude modulation by constructive or destructive interference of the two PA phase vectors.

The Effect of Outphasing on Apparent PA Load Impedance



- Mutual load pull from non-isolated amplifiers create load impedances on a clockwise and counter-clockwise semicircle

System Implications of Outphasing Modulation

- Transmitter modulation information is contained in two, phase-modulated drive signals, primarily residing in the first-order Bessel sidebands, requiring flat group-delay through driver circuitry

- The process to convert I-Q baseband information to appropriate phase-modulation is a non-linear operation with empirically-derived predistortion

- Retrofitting an existing transmitter system for a switching power amplifier involves insertion of circuit to extract amplitude, phase and frequency information from exciter RF output for conversion into phase modulated drive signals.

Outphasing Limitations

- Outphasing transmitters may use either an isolated or non-isolated combiner.

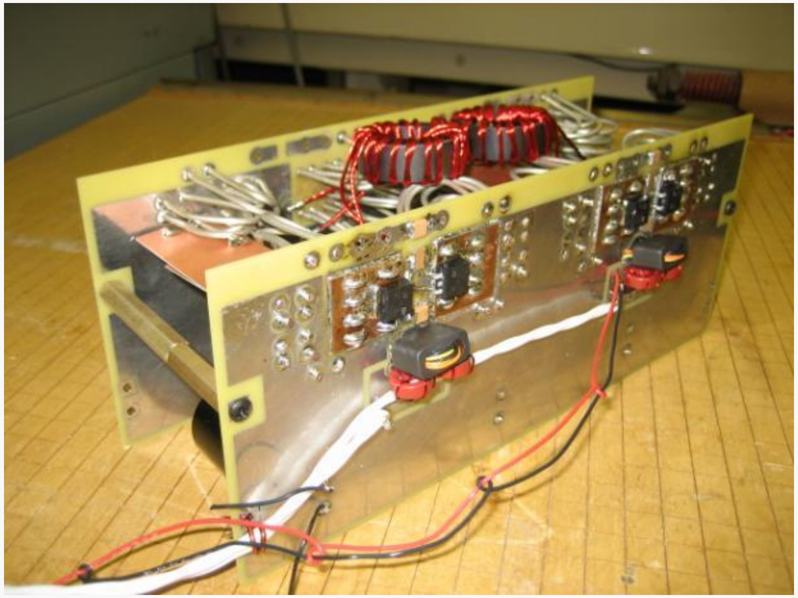
- An isolated combiner sends out-of-phase energy to a reject load, so that the PAs operate at a high-efficiency constant load, but combiner reject load, under modulation, dissipates at least as much power as antenna. System efficiency is similar to a Class-B PA.

- A non-isolated combiner modifies PA output through mutual load modulation of out-of-phase current. No power is wasted in a reject load, so efficiency can be nearly as good as an unmodulated PA, at the cost of added non-linearity.

- Non-linear relationship between phase difference and output amplitude dictates pre-distortion circuit in exciter/modulator.

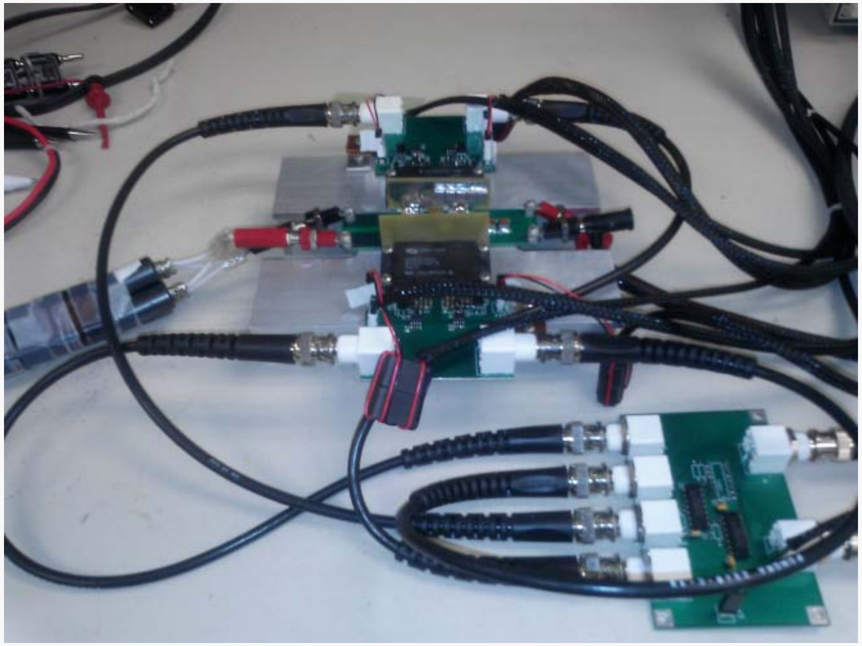
1.5 KW PEP Class D/E Outphasing HF Amplifier

- Eight, COTS SMPS MOSFETs in three-phase Class-D/E LINC configuration
- Demonstrated 94% drain efficiency at 1.5 kW, 10 MHz.
- Demonstrated 89% drain efficiency at 10.0 and 10.01 MHz two-tone test.
- Circuit is quasi-broad-band, operating within a half-octave sub-band.

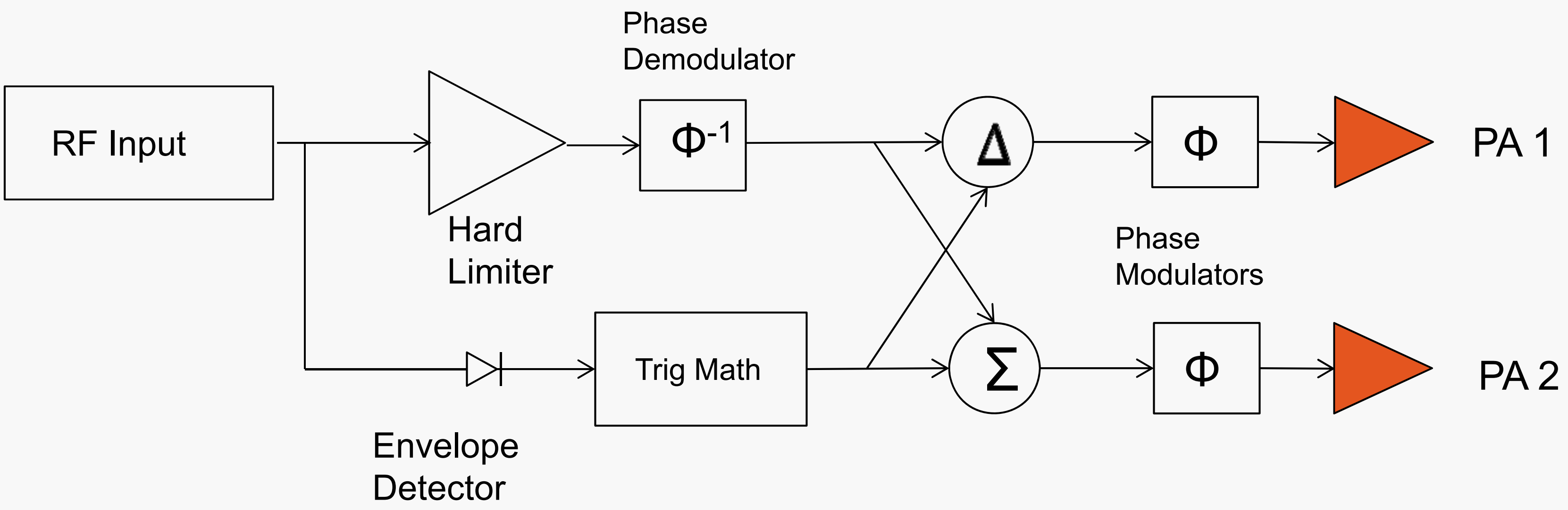


1 KW PEP Class D HF Outphasing PA

- Utilizes two, COTS SMPS MOSFET modules in broadband circuit.
- Demonstrated 1.0 kW PEP, 92% drain efficiency, 3 to 20 MHz
- Demonstrated half-octave modulation, 5.0 MHz and 7.1 MHz two-carrier, 1.0 kW PEP at 68% drain efficiency.

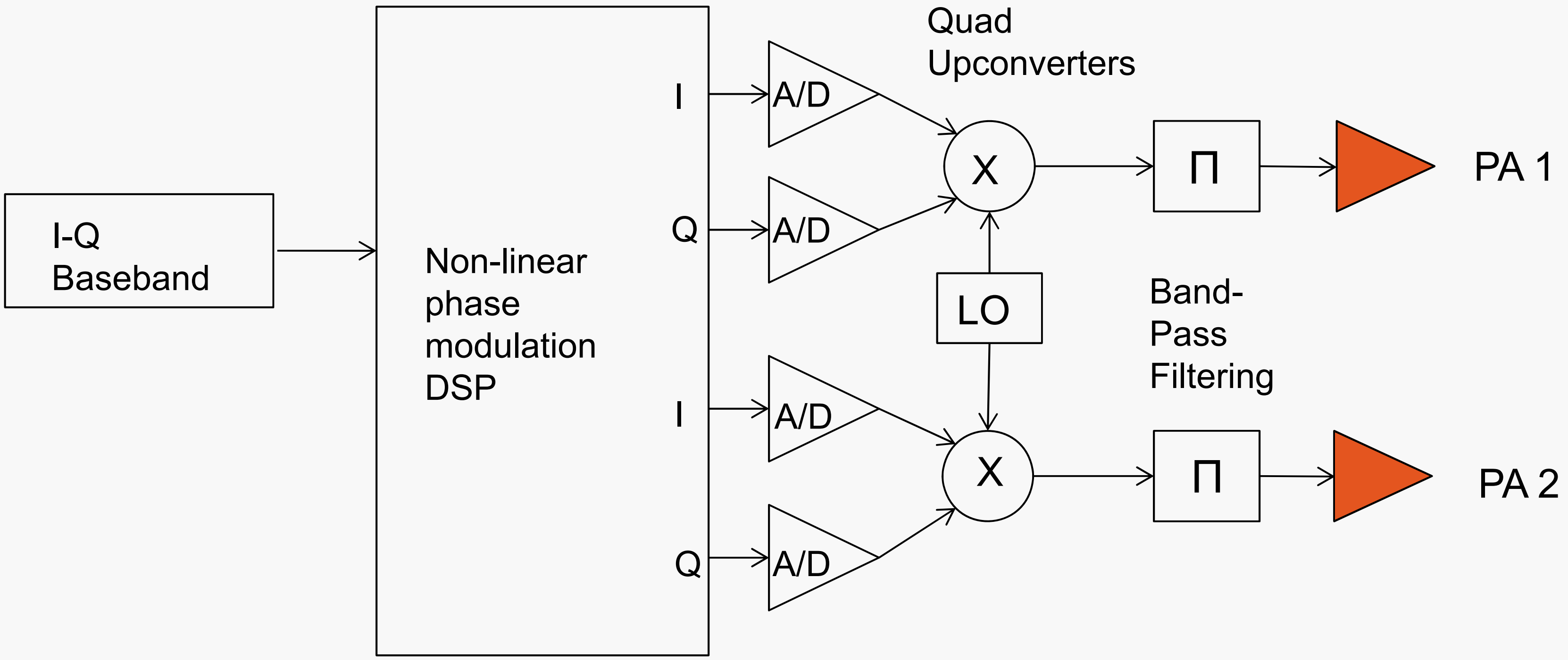


Retrofit Outphasing Modulator – Block Diagram



- The process of creating phase-modulated outphasing PA drive signals requires demodulation of amplitude and phase information from the exciter output.
- A more efficient approach is to perform all signal processing on I, Q in the digital domain, and then upconvert.

Suggested Outphasing Modulator – Block Diagram



- Performing all non-linear math and predistortion in DSP is a more efficient, straight-forward process.

Implications to Future Development:

- The unique drive signals required have implications on the architecture of exciter/modulator circuitry.
- The PA drive signals for both EER and Outphasing PAs are constant amplitude, phase modulated carriers
- Non-linearity of PAs dictates inclusion of digital pre-distortion
- Signals should remain in the digital domain as long as possible within the transmit signal chain.

Conclusions:

- High efficiency and high bandwidth are attainable at HF using COTS components using switching power amplifier circuits

- A PA retrofit solution to existing systems is possible, though cumbersome.

- A preferred approach to the system design is to perform PA drive signal phase modulation and predistortion in the digital domain before A/D conversion and upconversion in a dedicated exciter/modulator DSP